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(54) Power and signal transmission using insulated conduit for permanent downhole installations

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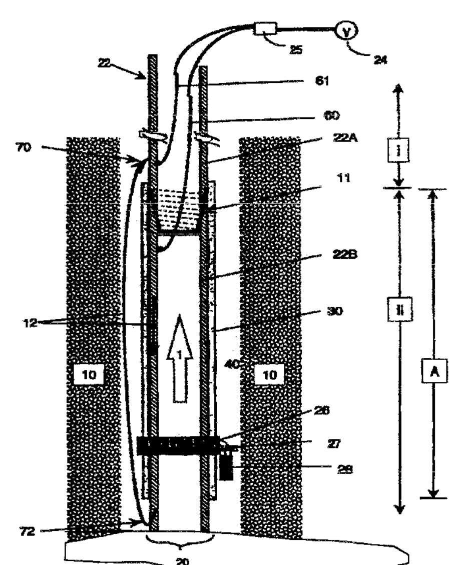

FIGURE 4

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 99 20 1789

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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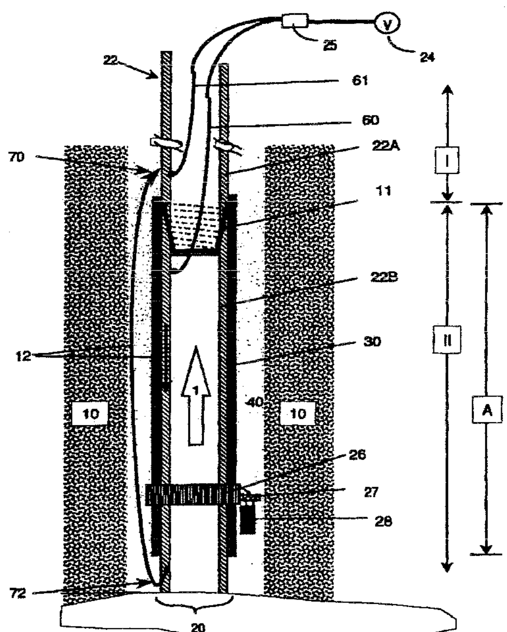

FIGURE 4

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minimal area resulting in localized high current density in the resistive earth, thereby generating heat. High current density is seen in heated zone H while very low current density is seen at surface return electrode R.

[0014] A simple surface return is utilized as there is no concern with overall system efficiency as far as electrical circulation is concerned. This type of system does not use the casing in conjunction with downhole electronics, i.e. for communication with or direct power transfer to downhole electronics, but rather focuses on the generation of heat in the formation via concentration of a large current flux at the end of the casing in zone H. Insulation is employed for current concentration in zone H by preventing injected current from flowing out of the casing to the surrounding formation except where desired- i.e., at the bottom of the well where the casing is exposed in zone H.

[0015] Several practical disadvantages are evident in such a system as that of Figure 3. One primary, and potentially dangerous disadvantage is that the wellhead is necessarily maintained at a very high potential in order to achieve the desired current density at well bottom to generate sufficient formation heating for their desired purposes. This can pose significant danger to the crew at the well site.

SUMMARY OF THE INVENTION

[0016] Limitations of the prior art are overcome by the method and apparatus of the present invention of power and signal transmission using insulated casing for permanent downhole installations as described hereinbelow.

[0017] The present invention is directed to various methods and apparatus for transmitting at least one electrical signal to or from at least one downhole device in a well. The method comprises providing an electrically conductive conduit in the well, electrically insulating a section of the conduit by encapsulating a section of the conduit with an insulative layer and insulating the encapsulated section of conduit from an adjoining section of the conduit by using a conduit gap, introducing the electrical signal within the insulated section of conduit, providing a return path for the electrical signal, and connecting the downhole device to the insulated section.

[0018] In alternative embodiments, the method includes introducing the electrical signal is performed via inductive coupling and/or direct coupling. The electrical signal includes power or communication signals.
The electrical signals can be introduced by one of the downhole devices or by a surface device, directly or inductively coupled to the insulated section of conduit.
The method may also include use of a second conduit gap to form a completely electrically insulated conduit section.
In the various embodiments, single or multiple devices may be coupled to the insulated section of conduit.
The return path for the electrical signal may be provided through the earth formation surrounding the well, through the cement annulus or through an outer conductive layer of the conductive conduit.
An apparatus is also disclosed for transmitting at least one electrical signal to or from at least one downhole device in a well. In various embodiments, the apparatus comprises an electrically conductive conduit installed in the well, insulation means for electrically insulating a section of the conduit, the insulation means comprising an insulative encapsulation layer around the section of the conduit and a conduit gap insulating the insulated section of the conduit from an adjoining section of the conduit, means for introducing the electrical signal within the insulated section of the conduit, means for providing a return path for the electrical signal, and means for electrically connecting the downhole device to the insulated section of the conduit.
In alternative embodiments, the apparatus comprises inductive coupling and/or direct coupling for introducing the electrical power or communication signals.
The electrical signals can be introduced by one of the downhole devices or by a surface device, directly or inductively coupled to the insulated section of conduit.
The apparatus may also comprise a second conduit gap to form a completely electrically insulated conduit section.
In the various embodiments, single or multiple devices may be coupled to the insulated section of conduit.
The return path for the electrical signal may be provided through the earth formation surrounding the well, through the cement annulus or through an outer conductive layer of the conductive conduit.

[0019] The foregoing and other features and advantages of the present invention will become more apparent in light of the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0020] The following drawings are referenced in the detailed description which follows and are provided to facilitate a better understanding of the invention disclosed herein.

Figure 1 illustrates a known wireless transmission apparatus.
Figure 2 illustrates known behavior of induced current.
Figure 3 illustrates a known apparatus for earth formation heating.
Figure 4 illustrates one embodiment of the present invention using an insulated casing with direct uphole and inductive downhole coupling.
Figure 5A illustrates an alternative embodiment of the present invention using an insulated casing with direct uphole and downhole coupling.

downhole via injection. Toroid 26 can be fitted and installed on a segment of casing 22 during casing manufacture, as can various measurement devices intended for permanent installation.

[0029] For communication to surface, the signal sensed by device 28 is encoded into a second alternating voltage in toroid 26 by downhole encoder circuit 27, at a frequency distinct from that of the injected current. This second voltage induces a second current in casing segment 22B, which also flows along illustrative current lines 12 and is detected by a surface electronic detector 25 where it is recorded, stored or otherwise processed as required.

[0030] Although not shown, multiple measurement devices (of the same or different type) with encoding/decoding circuits, and/or multiple toroids may be placed at various points (vertically) along the insulated casing (i.e., throughout region A). This allows a multitude of measurement devices to be distributed along the length of the well to accomplish diverse measurements. The encoder/decoder circuit 27 of each measurement device may additionally be equipped with an addressable circuit that allows instructions to be sent to, and measurement signals received from, individually controllable measurement devices.

[0031] While a typical cement annulus 40 has conductive properties, special highly conductive formulations of cement can be used to increase the conductivity of the cement so as to provide a more conductive path for currents. The use of highly conductive cement formulations has the advantage of providing a return path with controllable electrical characteristics. Use of specially formulated highly conductive cement will aid in performance and efficiency but is not critical and typical cement can none-the-less be used.

[0032] As for all embodiments described herein, the permanently installed conductive conduit includes at least an inner conductive member and an outer insulative layer. The conductive member can be either: 1) traditional metallic, preferable non-magnetic, conductive casing; 2) conductive production tubing; or, 3) other conductive liner installed permanently (usually via cementing) downhole (such as those described with respect to Figures 15-17 hereinbelow). The conduit is circumferentially encapsulated by an insulating layer over a specified region. For illustrative purposes and without the intent of imposing limitation, the various embodiments discussed herein utilize conductive casing or a combination of casing and tubing as the conduit conductive member. The insulating layer can be ceramic, plastic, fiberglass or other material preapplied to each casing section before it is shipped to the wellsite for installation or, alternatively, the insulating layer may be a coating, paint or wrapping pre-applied or to be applied on-site at the wellsite. A current source and return path are also provided as discussed with respect to the various embodiments herein. In the various embodiments herein, top and bottom electrode portions of the insulated conduit are exposed so as to allow the conductive conduit to electrically contact the surrounding cement annulus to provide a current source and return path. The principle of operation of the present invention remains unchanged regardless of the physical structure chosen as the conduit, the implementation of the insulating layer, the current source or return path

[0033] Figure 5A illustrates an alternative embodiment of the present invention where direct coupling is used for both current injection and connection to the downhole measurement device.

[0034] Similar to the embodiment of Figure 4, the conduit is implemented as a casing string 22 including casing segments 22A, 22B and 22C. Conduit gap 11 is placed within the casing string to provide electrical isolation between adjoining casing segments 22A and 22B. Second conduit gap 110 is located between adjoining casing segments 22B and 22C to provide electric zones I, II and III. The electric zones result from the electrical "gap" between casing segments 22A and 22B, and that between 22B and 22C, where casing segment 22A is electrically insulated from segment 22B by gap 11 and 22B electrically insulated from 22C by second gap 110. The insulative layer 30 extends beyond each gap 11, 110 to completely electrically insulate casing segment 22B. Current will flow though the conductive cement annulus 40 (and surrounding earth formation 10) between zone III and zone I (i.e., casing segments 22C and 22A) external to the insulated conductive conduit of region A.

[0035] Surface equipment (including voltage source 24 and encoder/decoder 25) is connected to the casing string 22 via a lines 60 and 61. The current is injected via line 60 into casing segment 22B with a return connection via line 61 connected to casing segment 22A.

[0036] Communications with and power to device 28 are provided via direct connection of downhole device 28 to casing 22 as illustrated in Figure 5B. Device 28 and casing segments 22B and 22C are connected in series, with independent connections via leads 28A and 28B on either side of gap 110 to casing segments 22B and 22C, respectively. Current from casing segment 22B will flow through device 28 to casing segment 22C.

[0037] Referring again to Figure 5A, the injected current will flow along illustrative current lines 12 through casing segment 22B, through device 28 to 22C, leaking into annulus 40 via bottom electrode 72 and seeking a return path to casing segment 22A through top (return) electrode 70.

[0038] The current injection connection, via line 60 to casing segment 22B in both Figures 4 and 5A is achieved downhole locally within the insulated region A, below gap 11. The return connection (via line 61 and casing segment 22A in both Figures 4 and 5A), on the other hand, can be achieved downhole or alternatively near the surface without any diminished performance as all casing segments above gap 11 back to the surface are electrically connected. Direct downhole casing con-

coupled to the conduit via toroids 26 and 26'. As in Figure 7, injection (i.e., connection of line 60) must be within insulated region A so as to inject a current which will flow in the conduit within region A and likewise toroids 26 and 26' must be placed within region A to capture the injected current.

[0051] Although not shown, addressable circuitry can be added to the encoder/decoder circuit 25 of surface equipment and 27, 27' of downhole devices 28 and 28' to effect independent communication and control of the individual downhole devices.

[0052] Additional various combinations including direct downhole device coupling and/or inductive injection coupling connections will also be understood.

[0053] Figure 9 illustrates one embodiment of the present invention in which insulated casing and inductive coupling is used for downhole power and two-way signal transmission.

[0054] Toroid 23 is used for current injection where a current is induced in casing 22 within insulated region A. Toroid 23 is linked to surface by a cable 60. Conduit gap 11 is used to form electrical zones I and II as previously discussed.

[0055] At the surface, electrical current is injected into toroid 23 via source 24 through cable 60, thereby inducing a current in casing 22 (by known electro-magnetic principles). The induced casing current flows along illustrative current paths 12 through the casing 22 where, at the bottom of the casing, via bottom electrode 72, the current leaks into the cement annulus 40 and flows through the annulus to the top (source and return) electrode 70.

[0056] Measurement device 28 receives electrical power from a toroid 26 on the outside of the casing 22 via induction where the aforementioned current flowing through the casing (here induced by toroid 23 as described above) inductively generates a voltage in the toroid 26 that is used to power the sensor. The toroid 26 can be fitted and installed on segments of casing 22 during casing manufacture, as can various measurement devices intended for permanent installation.

[0057] The signal sensed by measurement device 28 is encoded into a second alternating voltage in the toroid 26 by downhole encoder circuit 27, at a distinct frequency from that of the first injected current. This second voltage creates a second current in the casing 22, which also flows along illustrative current lines 12 and is detected by a surface electronic detector 25 where it is recorded, stored or otherwise processed.

[0058] Although not shown, multiple measurement devices (of the same or different type) with encoding/decoding circuits, and multiple toroids may be placed at various points along the insulated casing. This allows a multitude of measurement devices to be distributed along the length of the well to accomplish diverse measurements.

[0059] The encoder/decoder circuit 27 of each measurement device may additionally be equipped with an addressable circuit that allows instructions to be sent to, and measurement signals received from, individually controllable measurement devices.

[0060] Illustrated in Figure 10 is an alternative embodiment of the present invention where production tubing 18 is utilized as the conductive conduit and conventional (uninsulated) casing 22 is used as a return path for both communication with and power transmission to a downhole device 28.

[0061] Operationally similar to the embodiments of Figures 5A and 6, the conduit is implemented as production tubing string 18 including tubing segments 18A, 18B and 18C. Conduit gap 111 is placed within the tubing string to provide electrical isolation between tubing segments 18A and 18B. Second conduit gap 112 is located between tubing segments 18B and 18C to provide electrical zones I, II and III. The electrical zones result from the electrical "gap" between tubing segments 18A and 18B and 18B and 18C where tubing segment 18A is electrically insulated from segment 18B by gap 111 and 18B electrically insulated from 18C by gap 112. Zone II tubing (i.e., tubing segment 18B) is maintained in electrical isolation from casing 22 and is thus completely insulated electrically. This can be achieved in any of several known techniques such as providing an insulative layer around the tubing with the layer traversed or removed at connection to device 28, or by using, for example non-conductive centralizers (not shown) or non-conductive fluid in the interior annulus (i.e., the space between the tubing and casing) (not shown). Electrical connection is established between tubing segment 18C and casing 22 through conductive packer 71 for the current return path.

[0062] Surface equipment (including voltage source 24 and encoder/decoder 25) is connected to the tubing segment 18B and casing 22 via a lines 60 and 61, respectively. The current is injected via line 60 into tubing segment 18B with a return connection on line 61 connected to casing 22.

[0063] Direct connection of downhole device 28 to tubing 18 is used to communicate and provide power to device 28. Device 28 and the tubing segments 18B and 18C are connected in series, with independent connections via leads 28A and 28B on either side of gap 112 to tubing segments 18B and 18C, respectively. Current from tubing segment 18B will flow through device 28 to tubing segment 18C. The series connection is similar to that illustrated in Figure 5B.

[0064] The injected current will flow along illustrative current lines 12 through tubing segment 18B, through device 28 to tubing segment 18C, through conductive packer 71 along a return path in casing 22.

[0065] Direct downhole tubing connections such as discussed with respect to the embodiments of Figure 10 can be achieved in any suitable manner to assure good (i.e., low loss, efficient) electrical contact. One known technique is via landing devices. The injection connection, via line 60 to tubing segment 18B must be

(shown as casing 22 in the figure) is desirable. A minimum length l_c of layer 303 can be calculated based on factors including the distance d_c between contact points 60a, 61a, the expected conductivity of the fluid and the level of current to be injected (i.e., the potential expected between points 60a and 61a). A maximum length is not critical because a longer (than minimum) insulative layer 303 will result in a gain in efficiency.

[0083] The manner in which electrical isolation of the conduit sections is achieved is not essential and the implementation shown in the illustrative embodiment is not intended to be restrictive. It is important only to achieve the desired result of electrically isolating two joined (i.e., consecutive) sections of conduit on either side of the gap from each other.

[0084] Figure 15 shows an alternative embodiment of the present invention where the return circuit is provided by means of an additional conductive layer 140 applied to the outside of the insulating layer 130 on the conductive conduit, casing 122, forming a three-layer conductor-insulator-conductor "sandwich". The conductive layer 140 may be any conductive metal suitable for downhole use which applied to the outside of each insulated casing section before it is shipped to the wellsite; alternatively it could be in the form of a coating, paint or wrapping applied at the wellsite.

[0085] As shown in the drawing, insulative layer 130 is formed with an "overhanging" section 130a which will effect the conduit gap of the present invention.

[0086] The inner and outer conductors are electrically connected at some point during the run of the well so that current injected at the surface by source 24 via lines 60 and 61, through encoder/decoder 25, has a closed path within which to flow along illustrative current line 12. In this embodiment, the connection between inner and outer conductors is accomplished at the bottom of the well by shunt 150. A toroid 126 is disposed in the insulating layer 130, i.e., "sandwiched" between the inner conductive casing 122 and the outer conductive layer 140.

[0087] As in the earlier embodiments such as Figure 4, measurement device 28 is installed on the casing 122 along with encoder/decoder 27. Device 28 receives electrical power from toroid 126 where the current flowing through the casing 122 inductively generates a voltage in the toroid that is used to power the sensor. The device is connected to the toroid 126 via a lead through feed through nonconductive seal 160.

[0088] The signal sensed by measurement device 28 is encoded into a second alternating current in the toroid 126, at a frequency distinct from that of the current injected at the surface, thus creating a second current in casing 122 and conductive layer 140, which is decoded by surface electronic encoder/decoder 25 and recorded or otherwise processed.

[0089] Figure 16 illustrates another which utilizes direct downhole coupling. Like the embodiment of Figure 15, a three-layer "sandwich", comprising conductive casing 122, insulating layer 130 and a second conductive layer 140, is used

[0090] The two conductive elements 122 and 140 are insulated from each other by extending insulating layer 130 beyond the length of conductive casing 122 and into region 180, effecting a first conduit gap. As for the embodiment of Figure 15, an "overhanging" section 130a effects a second conduit gap.

[0091] An electrical power source 24, typically at surface and equipped with encoder/decoder 25, establishes a voltage potential across the two conductive elements 140 and 122 via lines 60 and 61. At various points along the well, measurement devices 28 measuring properties either inside or outside the well are connected across the two conductive elements as shown where insulating feed throughs 160 insulate and seal the area of the casing 122 through which a connection between measuring device 28 and the outer conductive layer 140 is made. The measurement devices 28 can be fitted and installed on segments of three-layer casing during casing manufacture to assure a reliable connection to the two conductive elements. Current flow will be through device 28 from casing 122 to outer conductive layer 140.

[0092] The principle of operation of the alternative embodiment illustrated in Figure 17 is similar to that of the embodiment illustrated in Figure 16, with the conductive outer layer (140 of Figure 16) replaced by an annulus of conductive cement 40. The conductive casing 122 is covered with an insulating layer 130 which is surrounded by conductive cement annulus 40. The two conductive elements (casing 122 and cement annulus 40) are insulated from each other, by extending insulating layer 130 beyond the length of conductive casing 122 and into region 180 forming a first conduit gap and "overhanging" section 130a effecting a second conduit gap.

[0093] At the surface, a voltage generator 24, through encoder/decoder 25, electrically connected to the casing 122 and cement annulus 40 (by electrode 266) via lines 60 and 61, applies an electric potential across the casing 122 and the conductive cement 40. At various points along the well, measurement devices 28 are placed to measure physical properties either inside or outside the casing. Such devices derive their electrical input power from the potential difference between the casing 122 and the conductive cement 40 in a manner similar to that of the Figure 16 embodiment. In particular, the device 28 would have one power cable attached to the casing 122, and the other would pass via an insulating feed through 160 to an electrode 267 situated in the conductive cement 40. Current flow will be through device 28 from casing 122 to electrodes 267, through conductive cement 40 to electrode 266 as shown by illustrative current lines 12.

[0094] Electrodes 266 and 267 are illustrated as outer conductive layers or bands on limited segments of three-layer casing. These electrodes could also be

20. The method of claim 19 wherein the step of retrieving is performed by inductive coupling.

21. The method of claim 19 wherein the step of retrieving is performed by direct coupling.

22. The method of claim 1 wherein the step of introducing the electrical signal within the insulated section of conduit is performed via coupling through a second conductive conduit.

23. The method of any one of claims 1-14 further including the step of providing an outer electrically conductive layer on the insulated conduit.

24. The method of claim 23 wherein the return path for the electrical signal is through the outer conductive layer.

25. The method of any one of claims 1-24 wherein the conduit gap is disposed within the insulative layer.

26. An apparatus for transmitting at least one electrical signal to or from at least one downhole device in a well, the apparatus comprising:

- an electrically conductive conduit installed in the well;
- insulation means for electrically insulating a section of the conduit, the insulation means comprising an insulative encapsulation layer around the section of the conduit and a conduit gap insulating the insulated section of the conduit from an adjoining section of the conduit;
- means for introducing the electrical signal within the insulated section of the conduit;
- means for providing a return path for the electrical signal; and
- means for electrically connecting the downhole device to the insulated section of the conduit.

27. The apparatus of claim 26 wherein the means for introducing the signal employs inductive coupling.

28. The apparatus of claim 26 wherein the means for introducing the signal employs direct coupling.

29. The apparatus of claim 26 wherein the electrical signal includes power signals.

30. The apparatus of claim 26 wherein the electrical signal includes communication signals.

31. The apparatus of claim 30 wherein the electrical signal is sourced by the downhole device.

32. The apparatus of claim 30 wherein the electrical signal is sourced by a surface device.

33. The apparatus of claim 31 wherein the surface device is connected to the insulated section via inductive coupling

34. The apparatus of claim 31 wherein the surface device is directly coupled to the insulated section.

35. The apparatus of claim 26 wherein the insulation means further comprises a second conduit gap disposed to form a completely electrically insulated conduit section.

36. The apparatus of claim 35 wherein the surface device is inductively coupled to the insulated section.

37. The apparatus of claim 35 wherein the surface device is directly coupled to the insulated section.

38. The apparatus of claim 35 wherein the downhole device is inductively coupled to the insulated section.

39. The apparatus of claim 35 wherein the downhole device is directly coupled to the insulated section.

40. The apparatus of any one of claims 26-39 wherein the return path for the electrical signal is through the earth formation surrounding the well.

41. The apparatus of any one of claims 26-39 wherein the conductive conduit comprises electrically conductive casing permanently installed in the well via cementation.

42. The apparatus of claim 41 wherein the cement is of a highly conductive formulation.

43. The apparatus of claim 41 or 42 wherein the return path for the electrical signal is through the cement.

44. The apparatus of claim 43 further comprising means for retrieving the electric signal from the insulated section of conduit.

45. The apparatus of claim 44 wherein the means for retrieving comprises inductive coupling.

46. The apparatus of claim 44 wherein the means for retrieving comprises direct coupling.

47. The apparatus of any one of claims 26-46 wherein the means for introducing the electrical signal within the insulated section of conduit comprises a second conductive conduit.

48. The apparatus of any one of claims 26-39 wherein the conductive conduit further comprises an outer

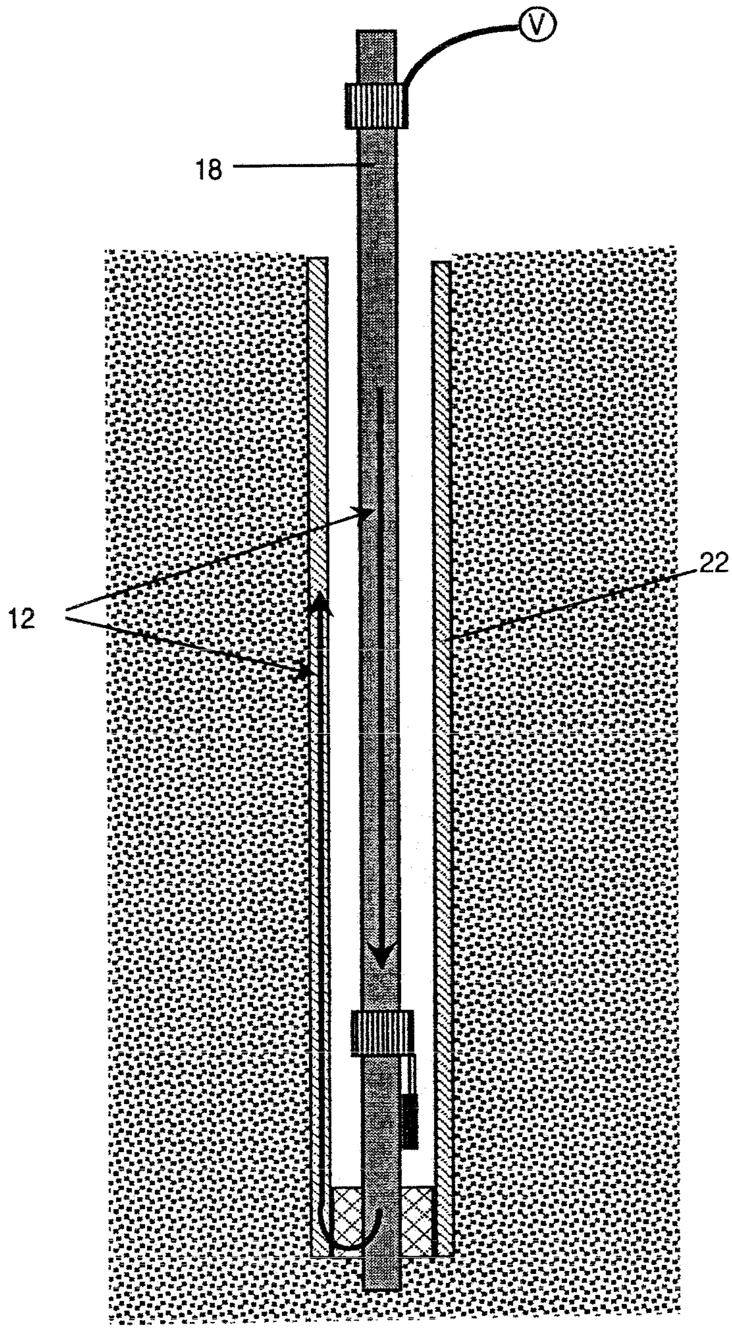

FIGURE 1
Prior Art

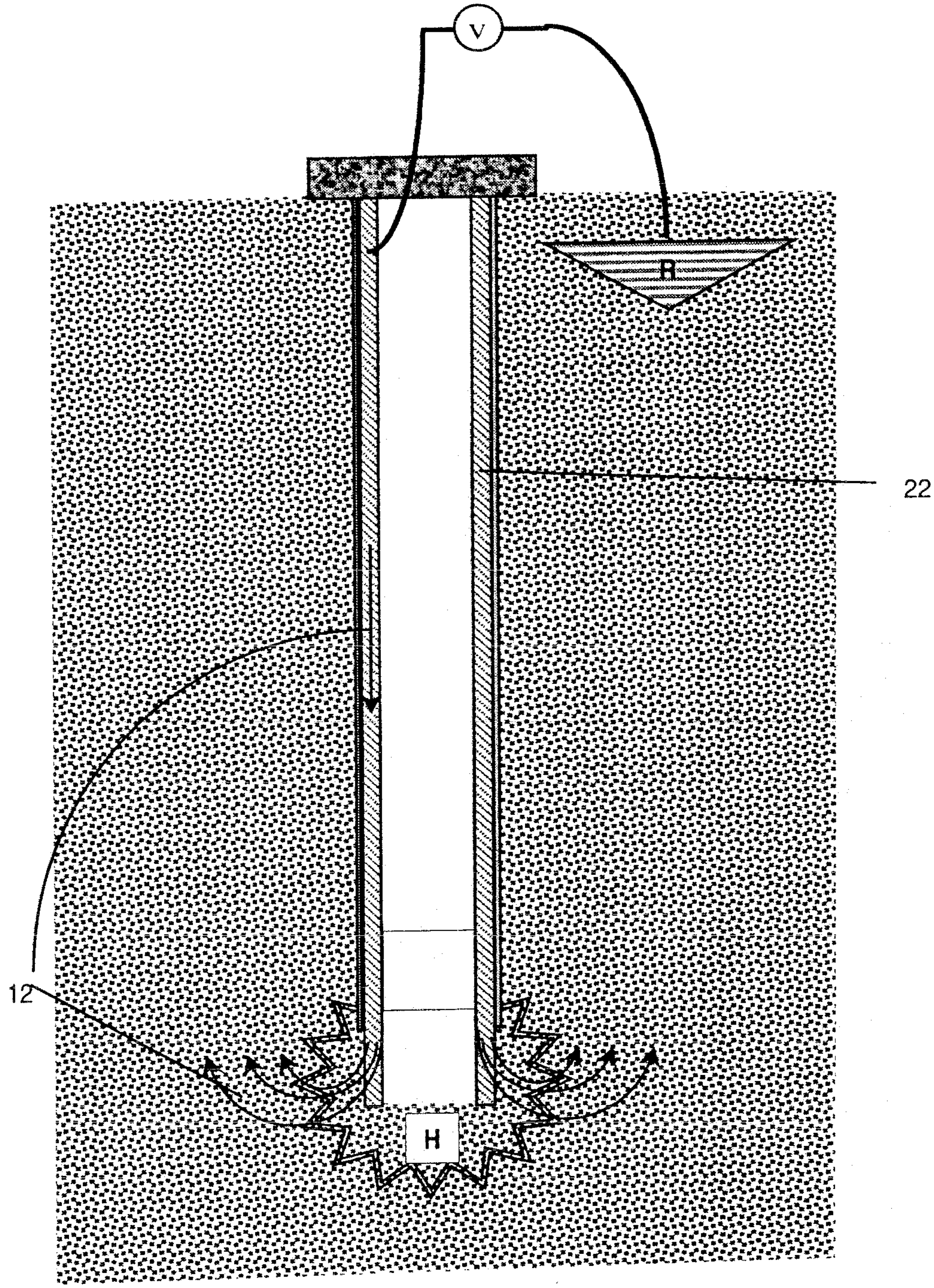

FIGURE 3
Prior Art

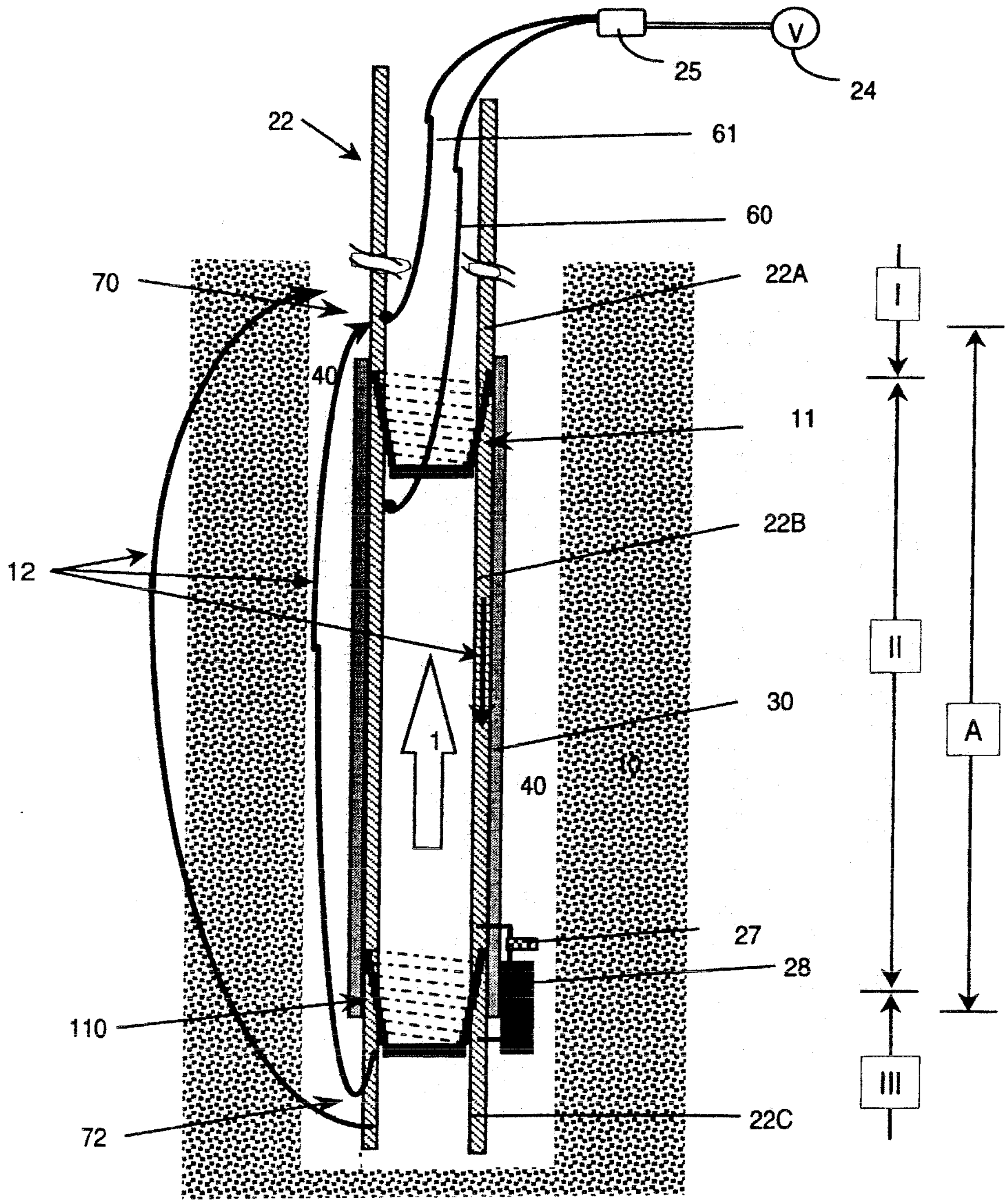
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FIGURE 5A

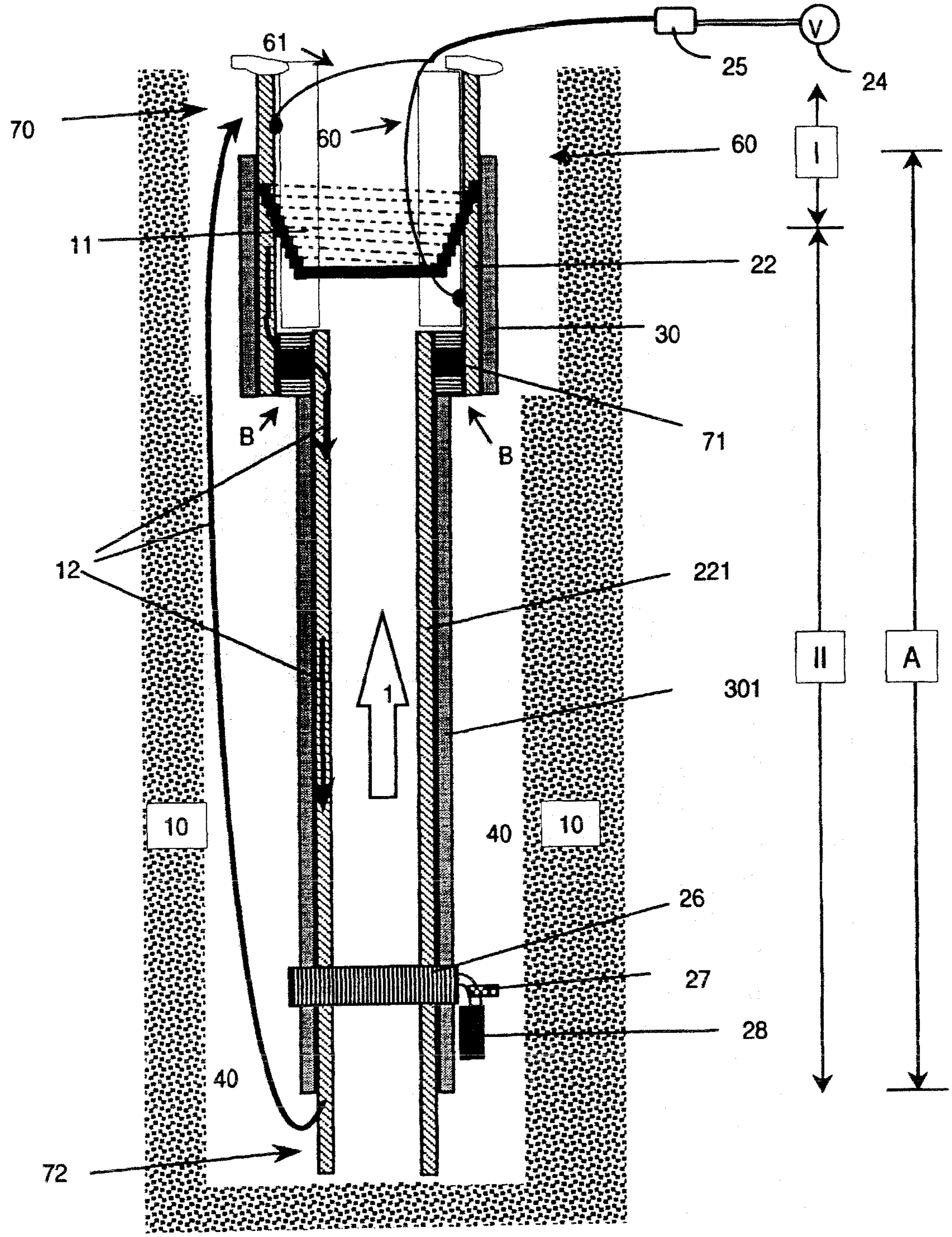
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FIGURE 7

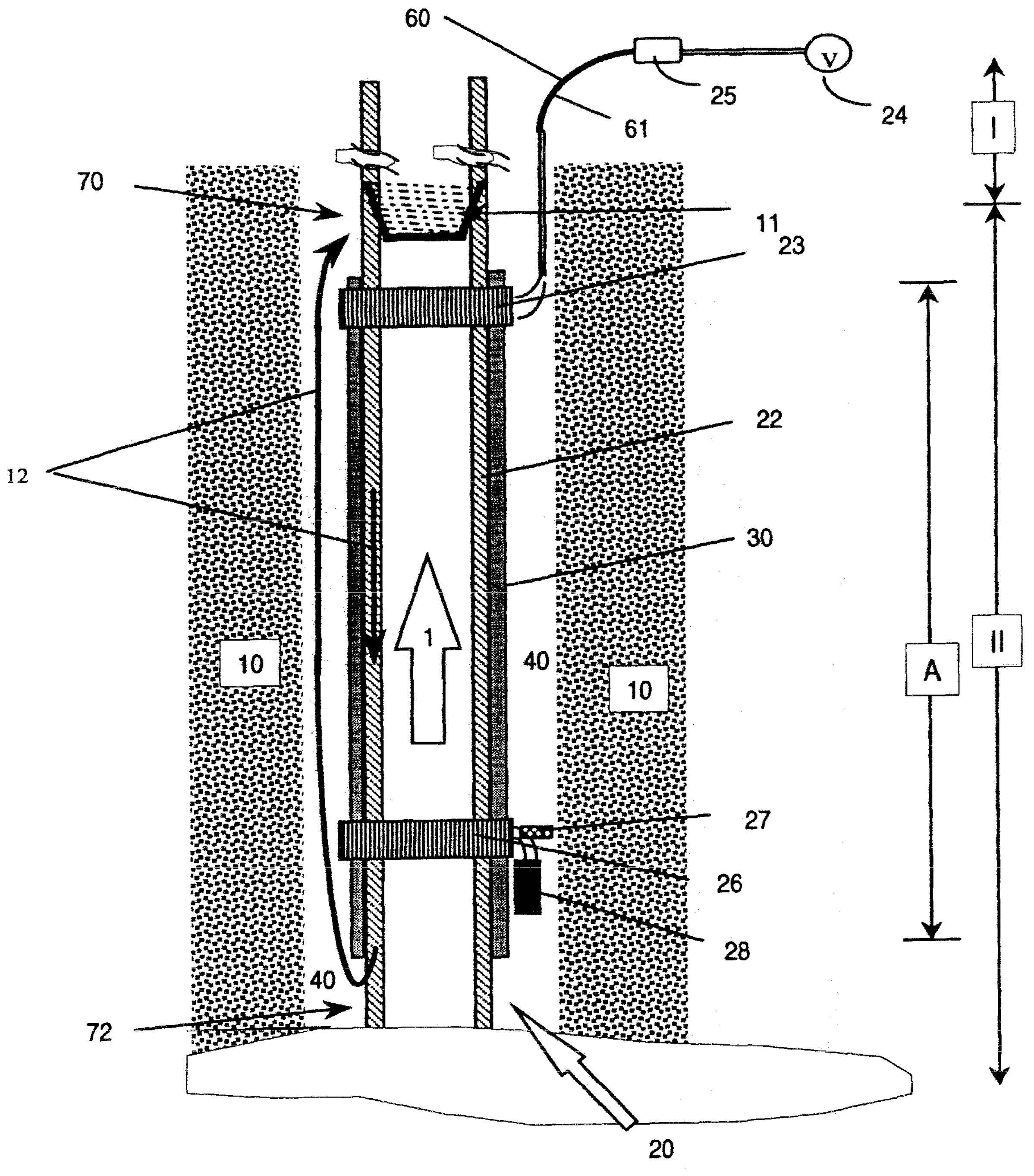


FIGURE 9

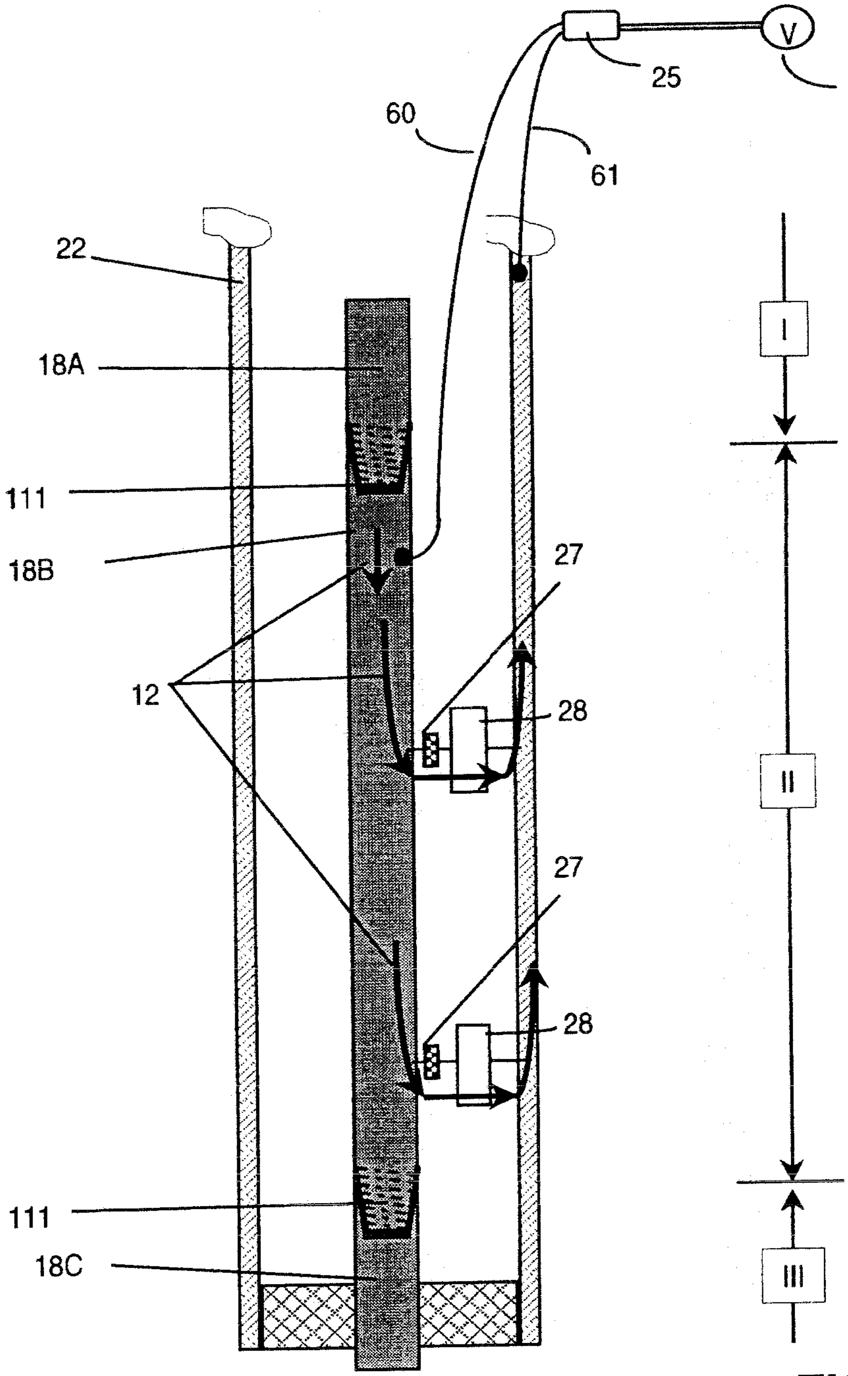
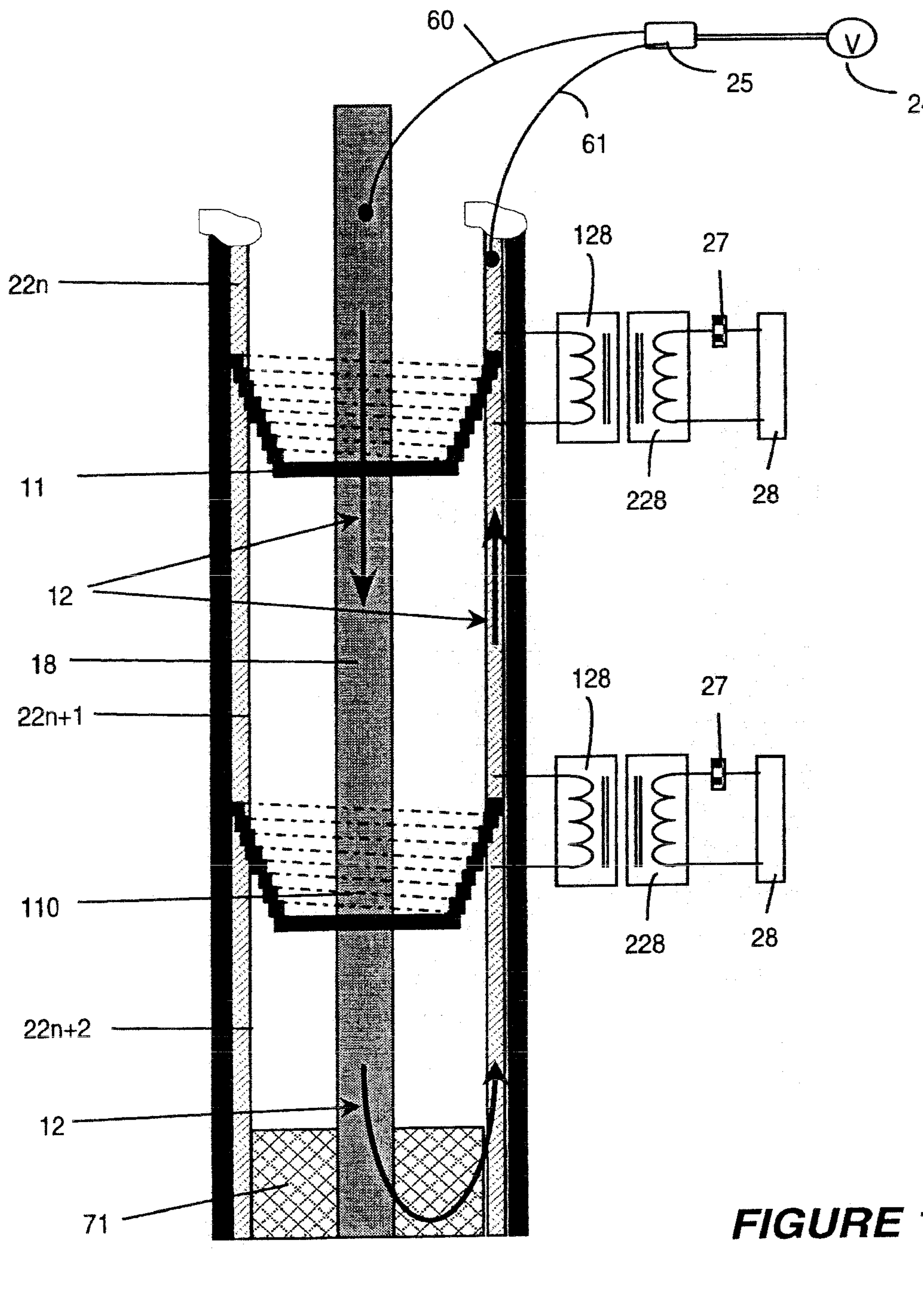


FIGURE 11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V
61
128
27
22n
228
28
11
12
18
22n+1
128
27
110
228
28
22n+2
12
71

FIGURE 13

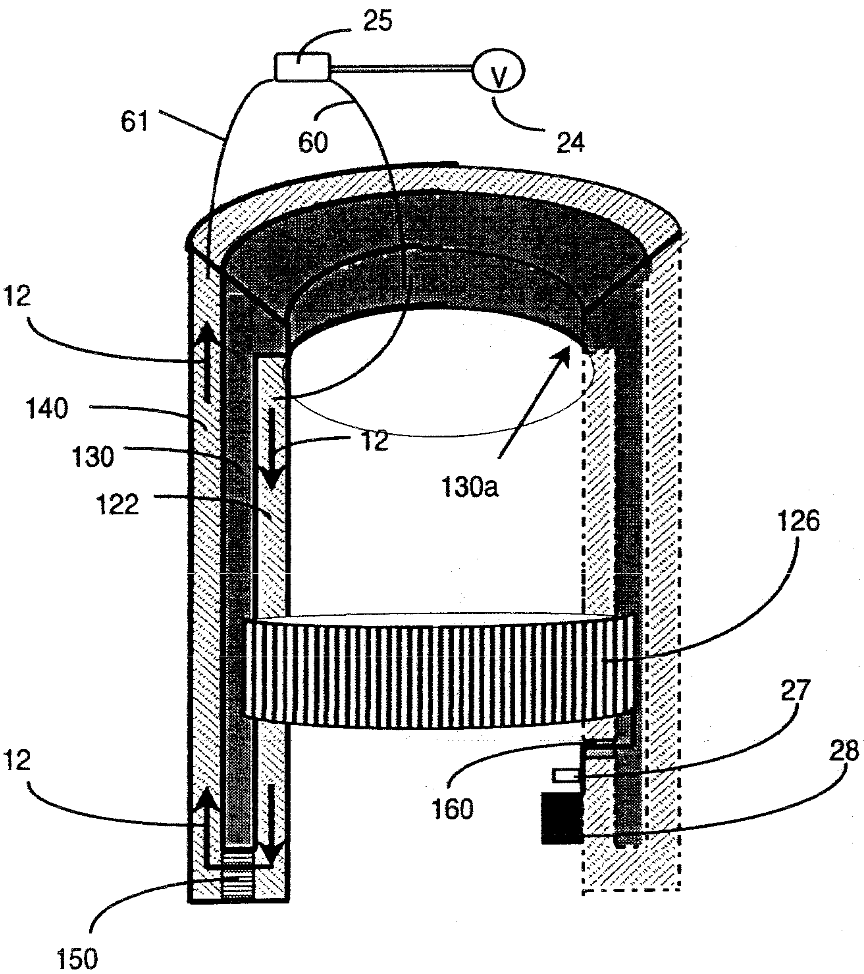

FIGURE 15

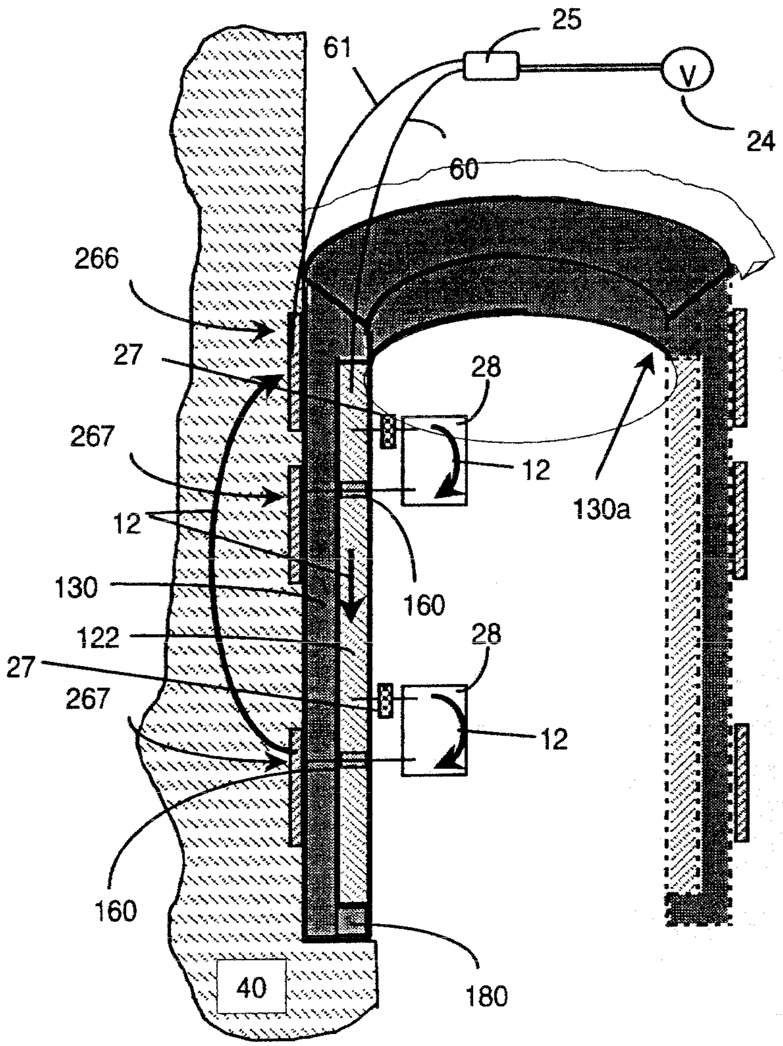
25
61
24
60
266
27
28
267
12
12
130a
130
160
122
28
27
267
12
160
40
180

FIGURE 17

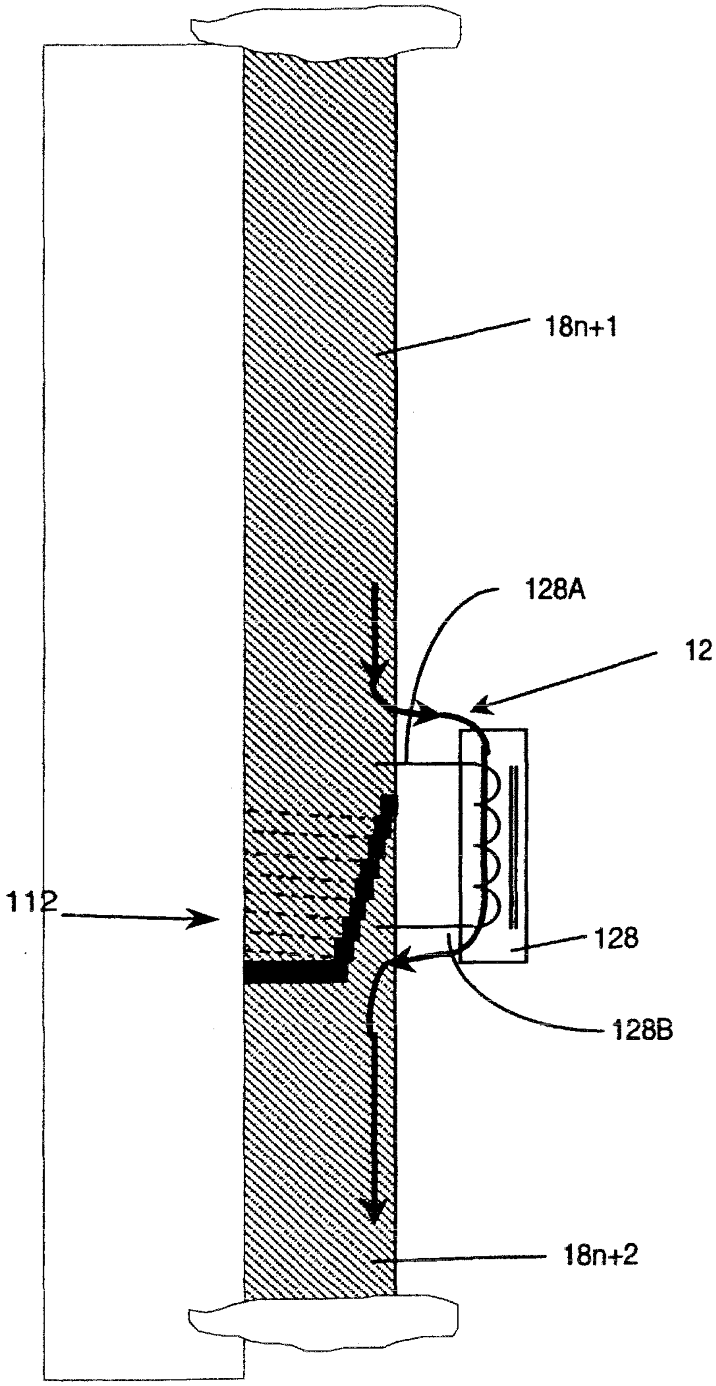

FIGURE 12B